Fast Engine Response Approaches and Test Bed

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Overview

- Past Work
- Fast Engine Response Approaches
- Conclusions
- Test Beds
- Acknowledgments

Problems identified with using throttles-only control (TOC)

- Past flight testing at NASA Dryden identified several problems with using only throttles for flight control
  - weak control moments
  - difficulty in damping phugoid and dutch-roll oscillations
  - coupling between pitch and roll
  - sluggish engine response that made landing extremely difficult

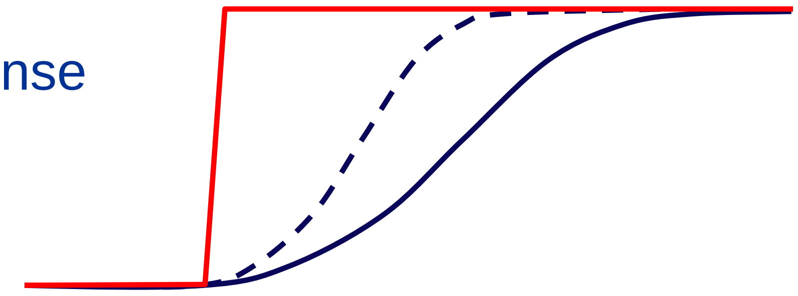
- Propulsion Controlled Aircraft (PCA), which is a flight control design using engines as actuators, might be a little better than pilot integration, but that is a flight control design problem. Faster engines can help there, too.

Fast Engine Response Approaches

- High speed idle
- Increase regulator bandwidth for small transients
- Control limit relaxation
- Adjustment of NDOT acceleration schedule
- Addition of stall margin control mode
- New control modes, e.g., L1 Adaptive Control
- New actuators, e.g., fan bleed valve

Objective of this effort

- Goal:
  - Decrease throttle to thrust response time



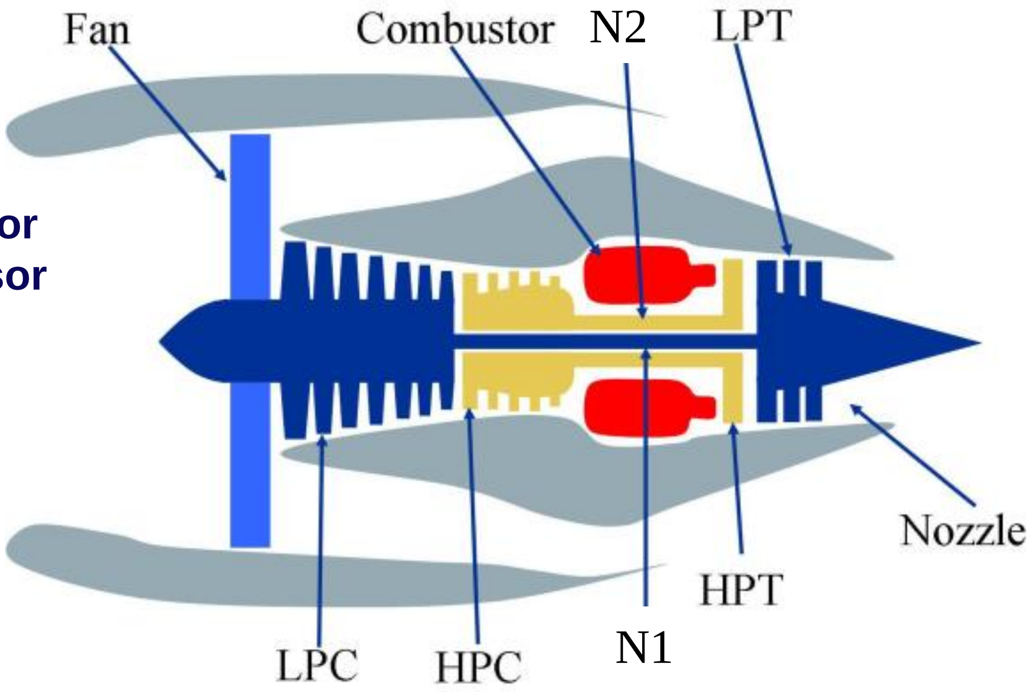
Throttle position

Thrust response

- Requirements:
  - Maintain engine conditions within minimum survivability limits (i.e. turbine temperature near but not exceeding blade melting point)
  - Ensure continuous engine operation when in “fast mode” (no stall)

What improvements can be made through modification of the existing controller?

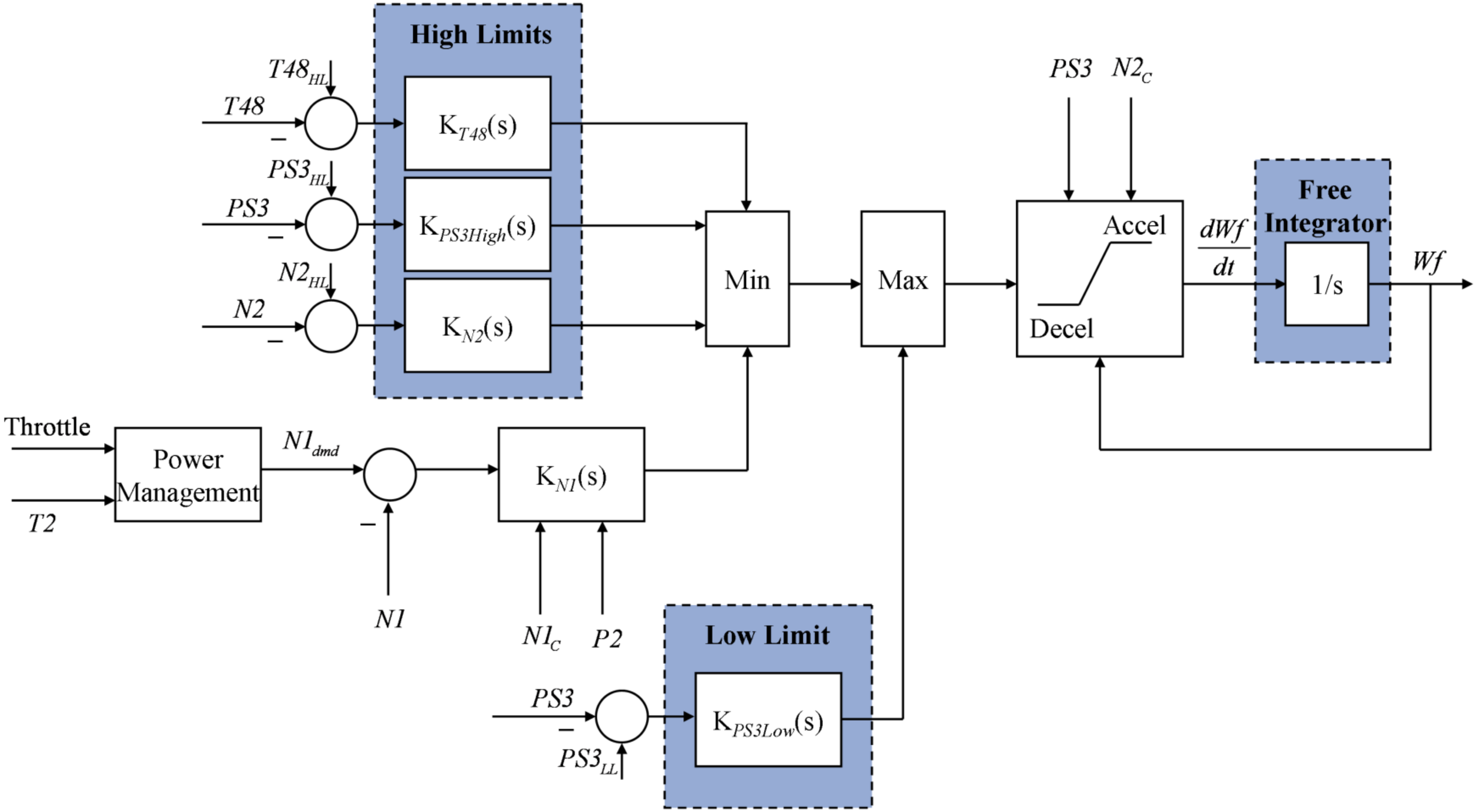
The Commercial Modular Aero-Propulsion System Simulation



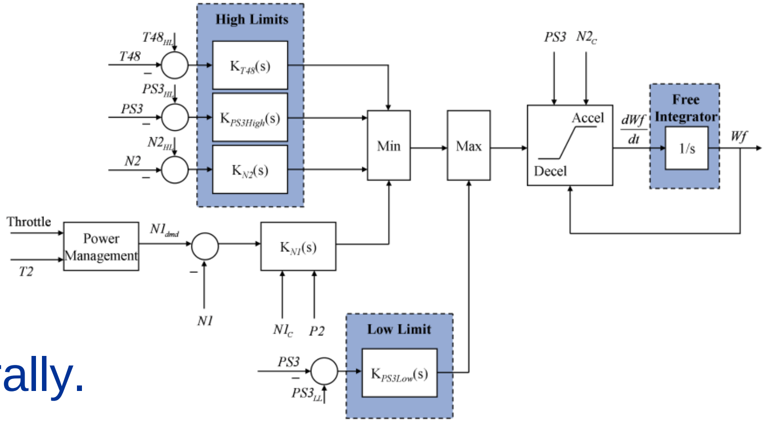
LPC = Low Pressure Compressor
HPC = High Pressure Compressor
HPT = High Pressure Turbine
LPT = Low Pressure Turbine
N1 = Fan Speed
N2 = Core Speed

C-MAPSS is available for download from the NASA Software Repository
https://technology.grc.nasa.gov/software/SWInfo_form.asp?cat=all&center=all&SwareKey=97

The C-MAPSS Controller is Representative of a Real Engine Controller



Features of the Controller

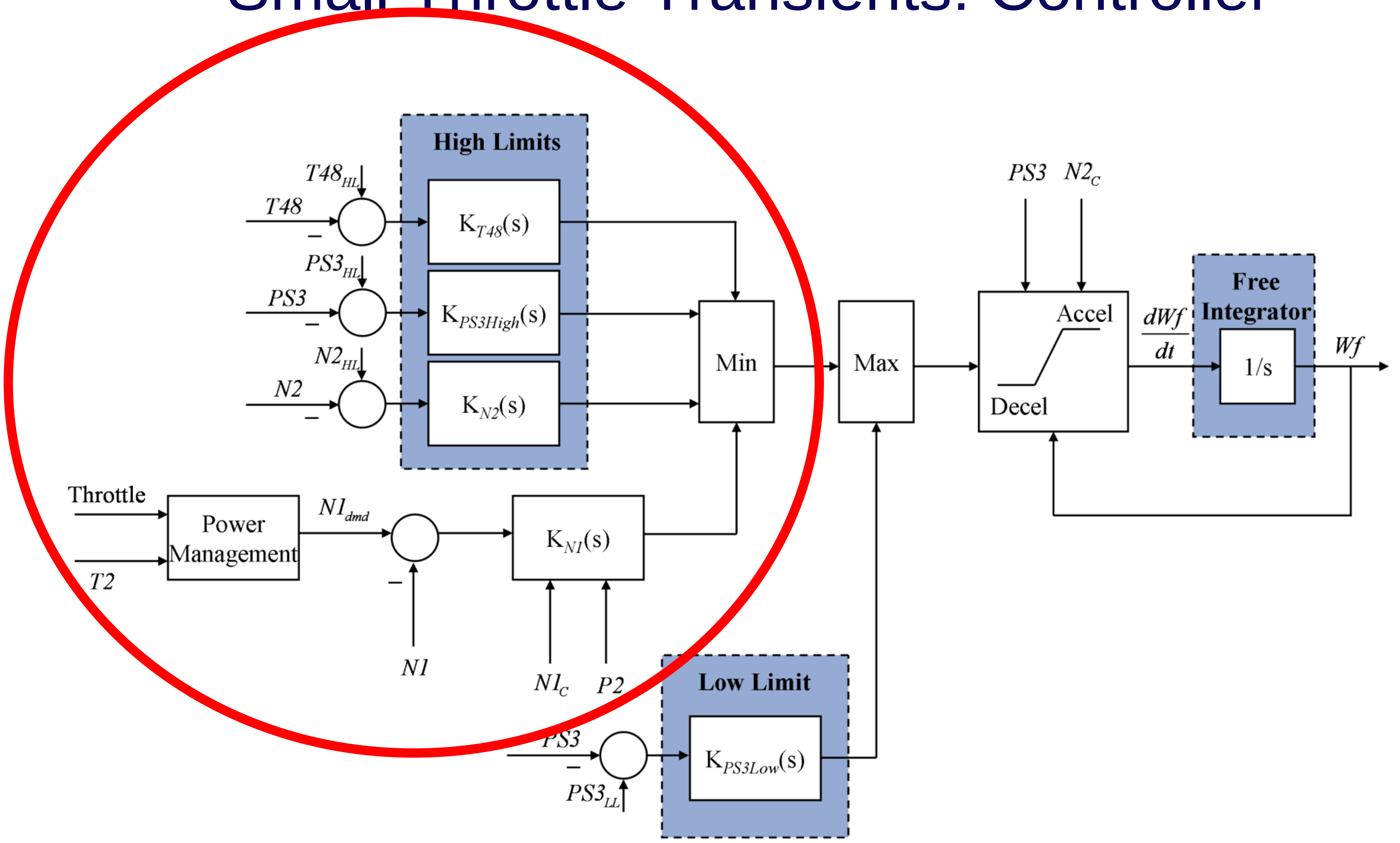


- Fan speed regulator
- High limit regulators
- Low limit regulators
- All regulators are linear gain-scheduled
- Limit regulators protect the engine structurally.
- C-MAPSS has temperature, pressure, and shaft speed limits
- Min/Max selection logic protects engine by selecting the most conservative fuel flow
- Acceleration/Deceleration schedules take over during large throttle movements. They protect the engine from stall and blowout
- All control signals are incremental fuel flow commands
- Free integrator adds increment to current fuel flow
- Eliminates integrator windup
- The controller is designed to provide safe engine operation over a long life, which means that it is designed to work for the most deteriorated engine under the worst conditions

Controller Bandwidth Increase/ Control Limit Relaxation/ Acceleration Schedule Relaxation Sensitivity Study

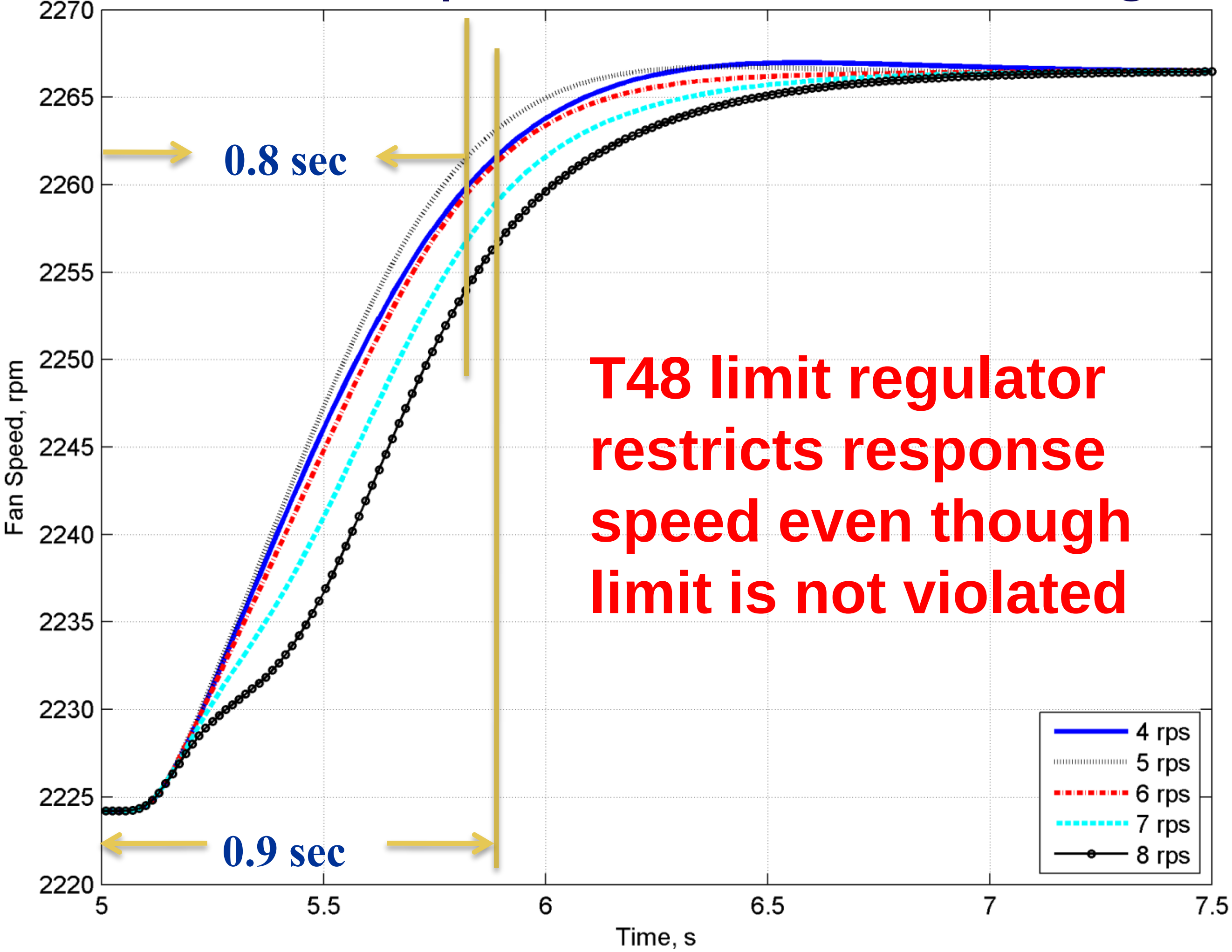
Ref: Litt, J.S., Frederick, D.K., Guo, T.-H., "The Case for Intelligent Propulsion Control for Fast Engine Response," AIAA-2009-1876, AIAA Infotech@Aerospace Conference, Seattle, WA, April 6-9, 2009

Small Throttle Transients: Controller



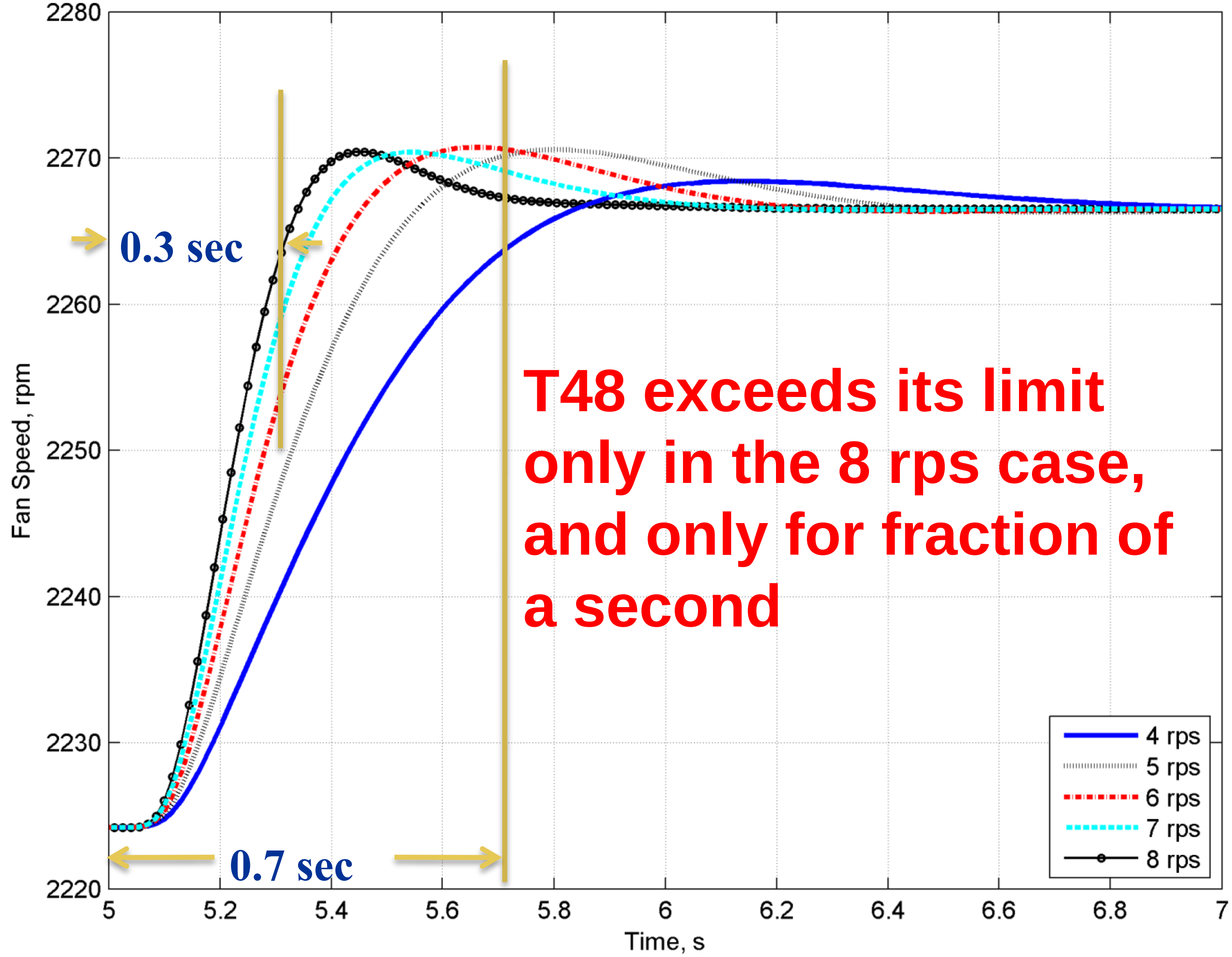
High limits protect the engine structurally

Small Throttle Transients: Throttle step of 5 degrees Closed loop bandwidth increasing

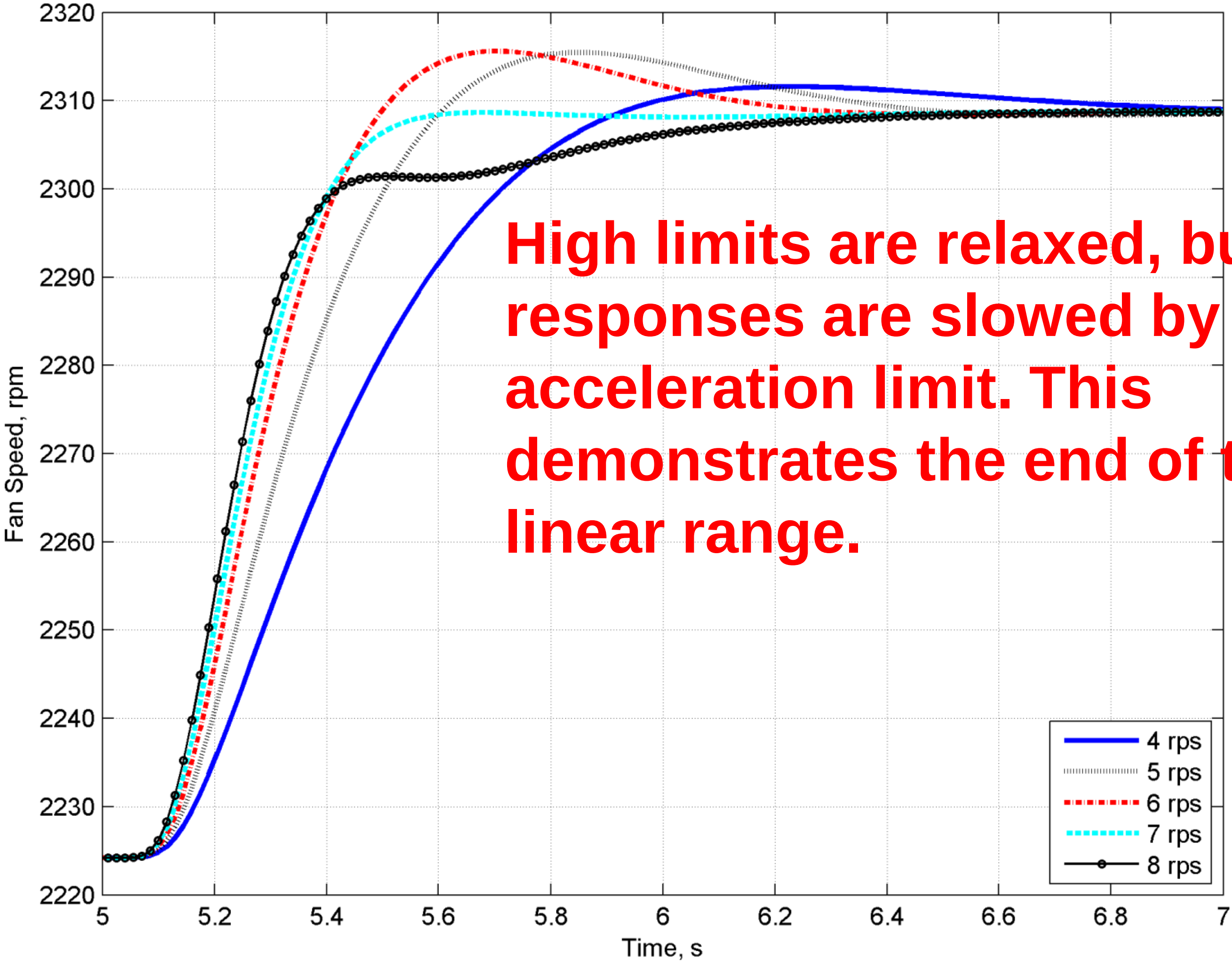


T48 limit regulator restricts response speed even though limit is not violated

Small Throttle Transients: Limits Relaxed
Closed loop bandwidth increasing

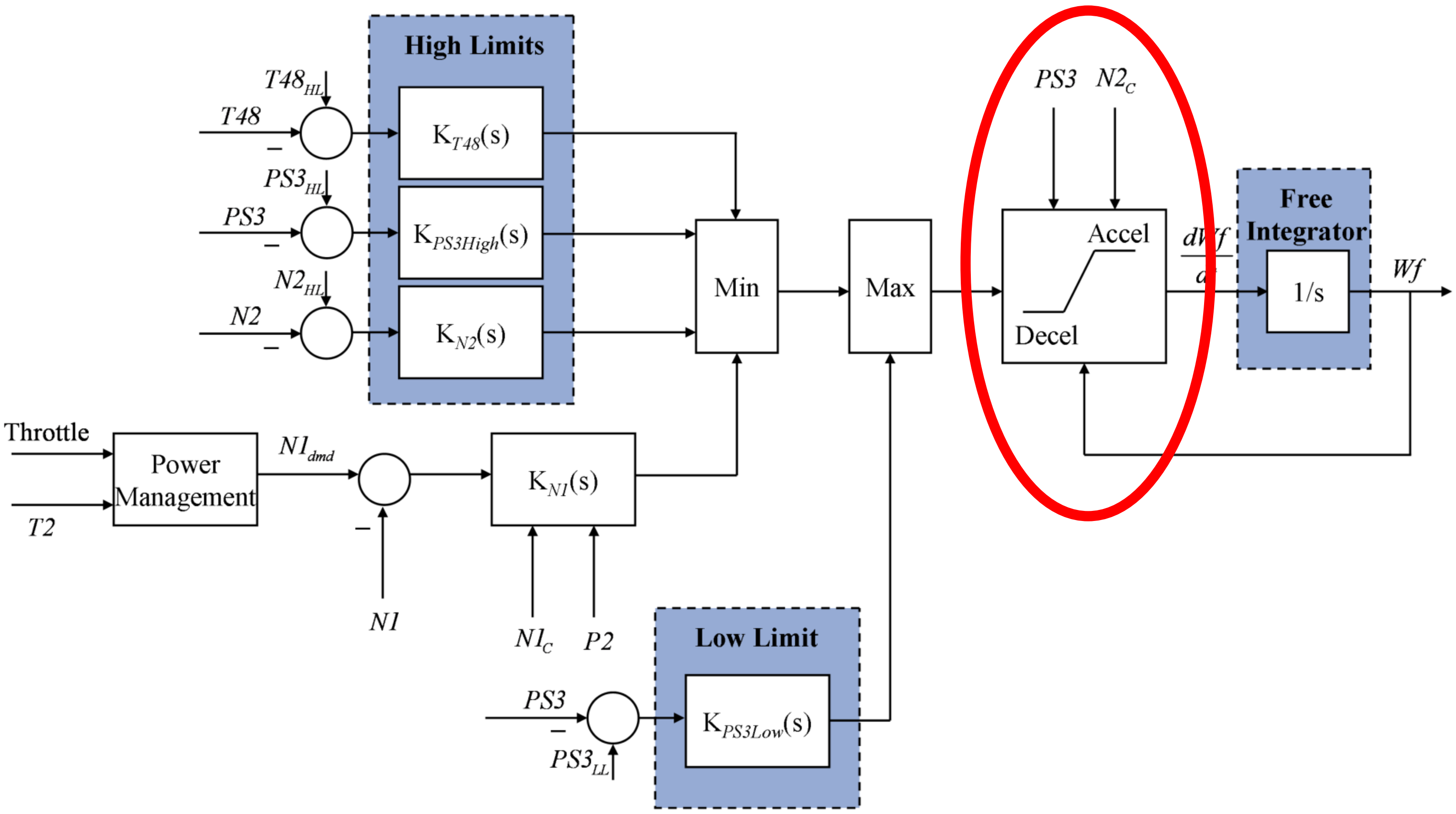


Small Throttle Transients: Throttle step of 10 degrees



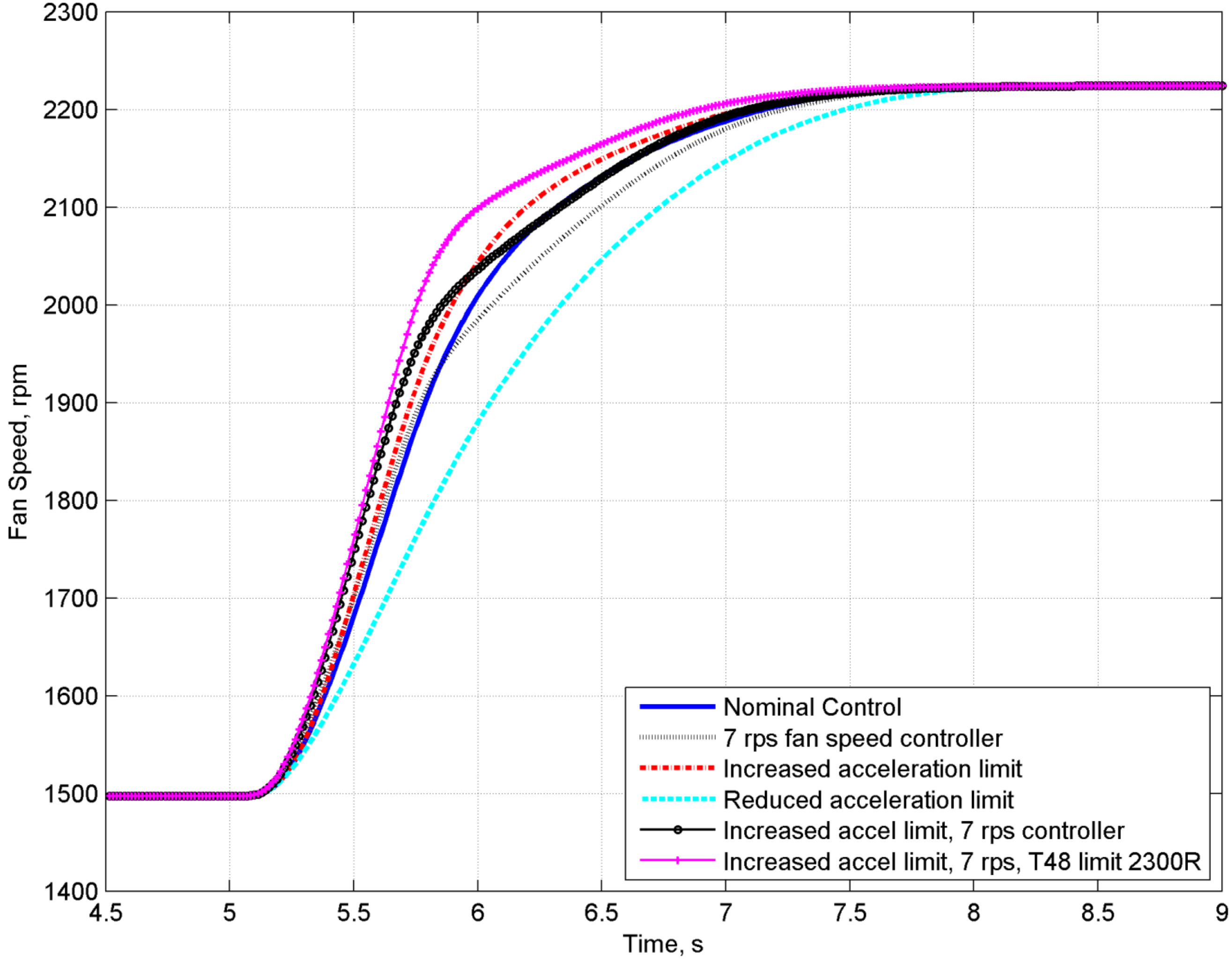
High limits are relaxed, but responses are slowed by acceleration limit. This demonstrates the end of the linear range.

Large Throttle Transients: Controller



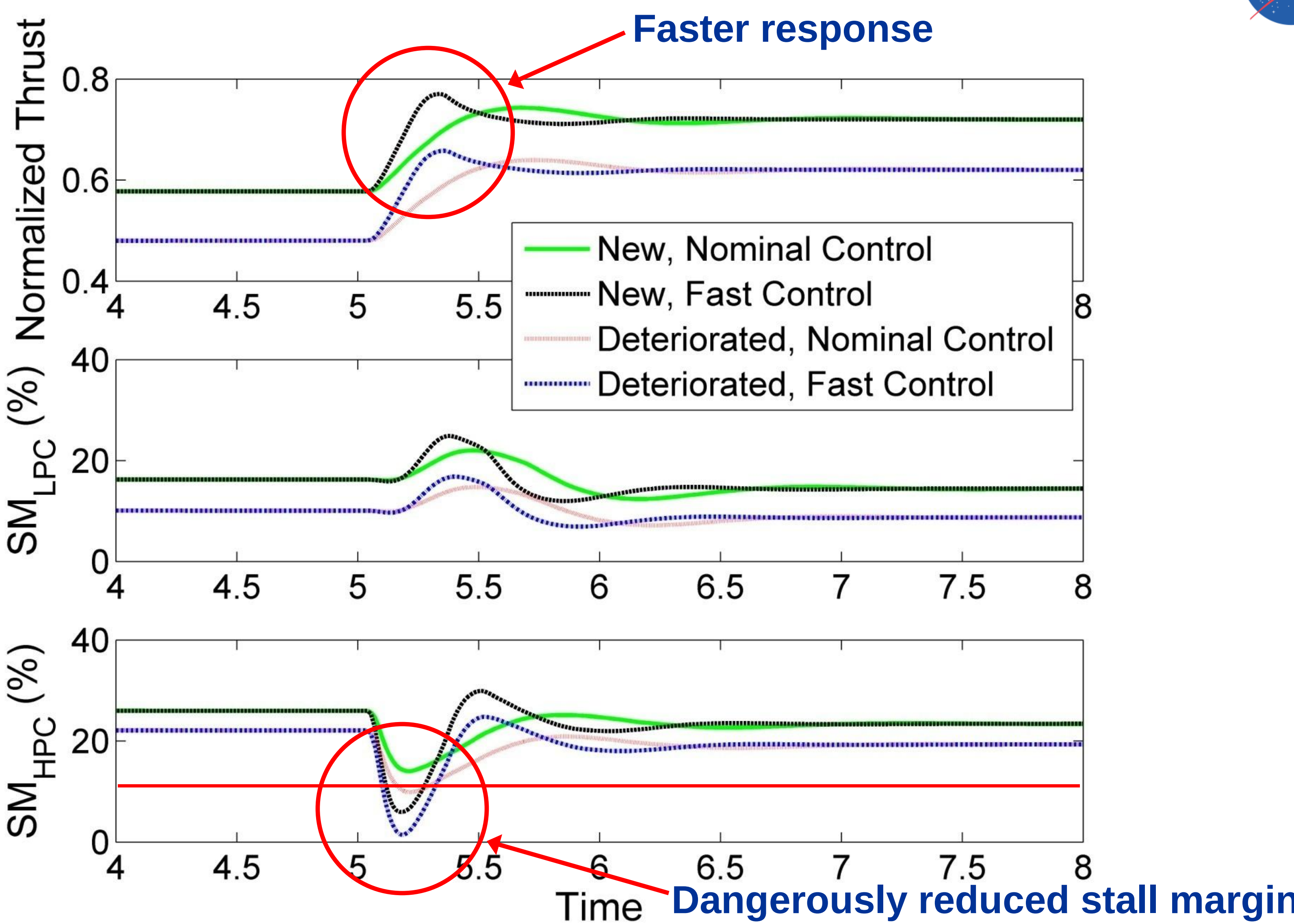
Acceleration limits protect engine from stall

Large Throttle Transients: Throttle step of 60 degrees Limits relaxed individually and in combination



Addition of stall margin control mode

- Parallel structure of limit regulators allows additional regulators to be added easily to existing control architecture
- Since stall margins are not measurable they must be estimated and these estimated values would be used as control variables



Litt, J.S., Guo, T.-H., "Fast Thrust Response for Improved Flight/Engine Control under Emergency Conditions," AIAA 2008-6503, AIAA Guidance, Navigation and Control Conference and Exhibit, Honolulu, Hawaii, August 18-21, 2008.

Conclusions

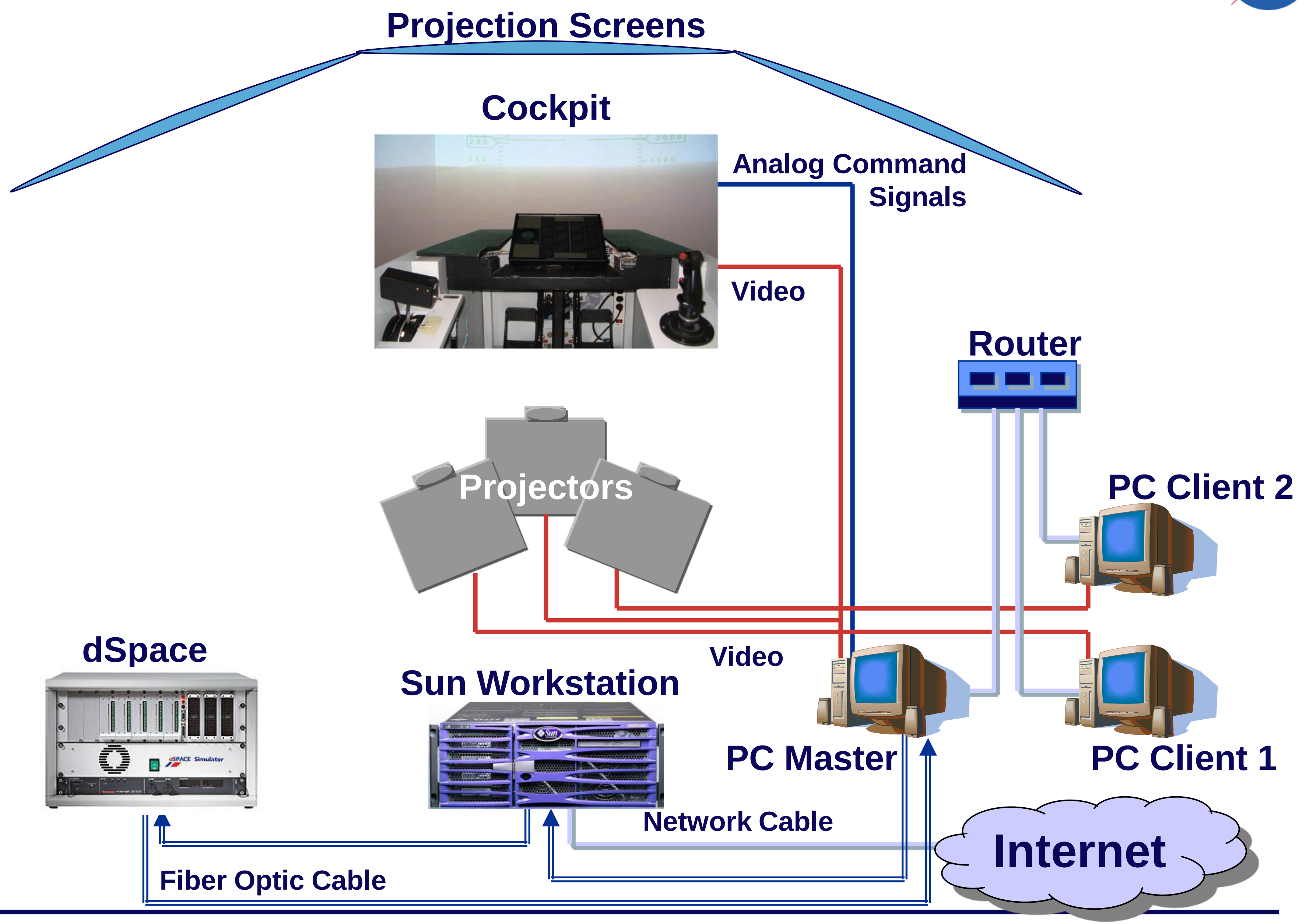
- Since the controller is designed to accommodate the worst case engine, some ability to improve thrust response almost always exists
- The use of estimated engine health information can enable more aggressive operation
- The controller schedule and limit adaptation procedure depends upon the level of deterioration of the engine and how the limits interact during transient operation, so it is condition- and situation-dependent
- The fast response control modes described are being or will be investigated using C-MAPSS40k

Test Beds

Test Beds

- NASA GRC Piloted Control Evaluation Facility
- Generic Transport Model (GTM)
- Boeing Flight Simulator
- NASA F/A-18

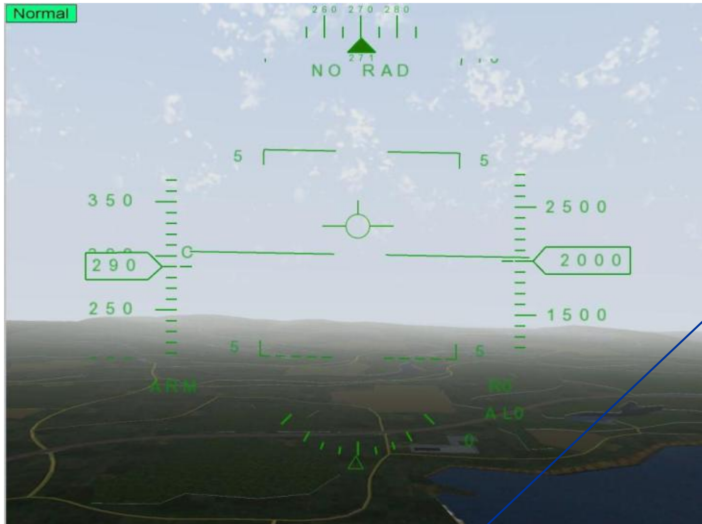
NASA GRC Piloted Control Evaluation Facility

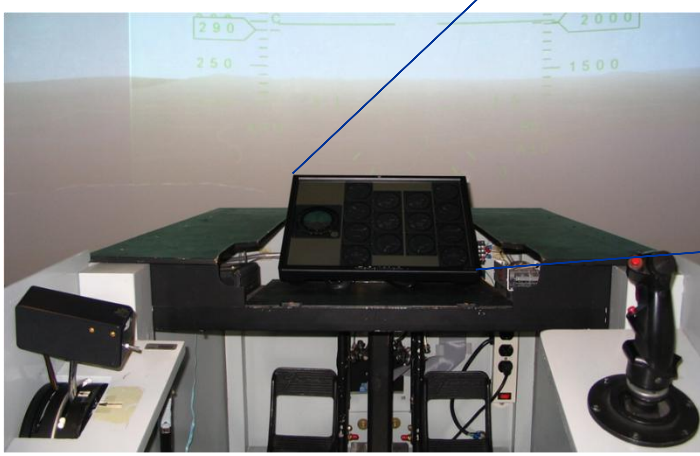


Computer Capabilities

- Sun Workstation runs nonlinear airframe simulation in real time.
- Three networked PCs run
  - Out the window scenery (three channels)
  - Four copies of C-MAPSS40k running in real time
- Software
  - Currently using GL Studio with Vega Prime
  - Investigating Microsoft ESP

Piloted Control Evaluation Facility





Acknowledgments

Fast Engine Response

– Dean K. Frederick, Saratoga Control Systems, Inc.

Test bed

– T. Shane Sowers, QinetiQ